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DETONATION CHARACTERISTICS OF DUST DISPERSED IN AIR.(U)

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DETONATION CHARACTERISTICS OF  
DUSTS DISPERSED IN AIR

by

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prepared for

Directorate of Aerospace Sciences  
Air Force Office of Scientific Research (AFSC)  
Bolling Air Force Base, D.C. 20332

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br><br>This study is aimed at determining, experimentally and analytically, the detonation properties of high explosive dust when dispersed in air. The experimental facility, which is a modified form of a shock tube, is described. The experimental results obtained when a strong blast wave is transmitted into plastic coated RDX-air, RDX-nitrogen, and RDX-oxygen mixtures are described. Two sizes of particles were tested and the larger (about 150 $\mu$ m) appeared to be easier to detonate than the smaller particles (about 10 $\mu$ m). Ignition was |  |  |

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observed in nitrogen but only after a long time delay. Calculated values of the detonation properties of RDX-air and various RDX-liquid fuel combinations in air are presented. The results of a numerical code prediction of the variation of pressure with distance behind the blast wave, as well as the structure of the detonation wave, are also presented.

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## STATEMENT OF WORK

The objective of this study is to determine the detonation properties of high explosive dusts when dispersed in air. Towards that end, the Grantee shall conduct an experimental and analytical study which should include the following elements:

1. Design, procure, assemble, and operate a suitable experimental apparatus.
2. Conduct a number of tests with RDX dust dispersed in air. A couple of particle sizes and range of mass loadings will be tested. Information relative to wave velocities, pressure variations, wave structure (by high speed photography), minimum initiation energy for detonation, and the lean detonation limit will be determined.
3. Analytical work will be conducted so as to interpret the experimental results in terms of theoretically predicted Chapman-Jouquet properties and to explain the reaction zone mechanism. A comparison will be made between the experimental measurements and the theoretical prediction of impulse.

## STATUS OF THE RESEARCH EFFORT

### Experimental Facility

In order to experimentally determine the desired detonation properties, a facility was designed, built, and operated in the first year of the program and then improved upon in the second year. The main part of the facility is shown in Fig. 1. The driver section, which is separated from the transition section by a diaphragm, consists of a 5 ft length of heavy wall 3 in. ID circular tubing. It is charged with a high pressure hydrogen-oxygen-helium ( $2H_2 + O_2 + 1.5 He$ ) mixture derived from a large pre-mix tank. At the appropriate time the mixture is detonated by a glow plug with the result that a blast wave is transmitted through the transition section and into the test (driven) section. The transition section adapts the circular driver to the rectangular driven section. Also, the dust is picked up from a feeder and introduced in the downstream direction by means of a carrier air (or oxygen) flow. Other airflow is also introduced in this

section. The original feeder was destroyed by an explosion and a new design was successfully used during the past year. A sketch and photograph of this feeder is shown in Fig. 2. The driven (test) section is a 20 ft long rectangular stainless steel tube of internal dimensions 1.5 x 2.5 in. The instrumentation is indicated in the figure wherein the pressure switches yield wave arrival times and hence wave velocity. During the past year additional pressure transducers were added so as to give a total of seven (7) in the test section. During operation of the tube, any reacted or unreacted mixture is conducted outside of the building, through a very large thick walled steel cylinder (2 ft diameter, 13 ft long), and into a sand pile. A burner is provided for the purpose of burning up any residual dust; however, it has not been found necessary to activate this in the more recent runs.

During the year a design was completed for the installation of windows so that photographic studies could be undertaken. However, the test section has not been machined for that purpose so far.

A couple of inadvertent explosions in the pre-mix tank, which was outfitted with a blowout diaphragm, were experienced which led to an appreciable down time. This tank was outside and buried under many feet of sand. A dual tank system, capable of sustaining the explosion, is being planned and developed.

#### Experimental Results

In order to work out the operating techniques and instrumentation, grain dust (wheat) was used at first. No detonation was realized even though pure oxygen was used on some runs. However, no attempt was made to dry the tube and it is believed that water vapor precluded detonation. The explosive dust used was plastic coated RDX-E and RDX-A, wherein the

former has an average particle size of 10  $\mu\text{m}$  and the latter of 150  $\mu\text{m}$ . Electron micrographs of the two are shown in Fig. 3.

For any given experiment, the wave position versus time data is obtained from the pressure switches. This data is converted to wave velocity, or Mach number, versus distance. The results of a calibration run (i.e. no dust) are shown in Fig. 4. The pressure plotted represents the maximum value immediately behind the wave front. In many cases the driver volume is reduced by putting a metal bar in it. Thus, for the run shown only 1/4 of the driver volume was used. The decay of wave strength with distance is obvious.

The variation of wave Mach number for the small sized RDX dust is shown in Fig. 5. Pure oxygen was passed through the feeder but the main convective flow was air. The concentration, 1100  $\text{gm}/\text{m}^3$ , is somewhat on the lean side. No detonation was realized, either in this case or others with the RDX-E. On the other hand, the larger size RDX-A was found to detonate, at least with some oxygen enrichment, as seen in Fig. 6. It is believed that the explanation for this lay in the fact that the larger particles will lag the gas velocity for a much longer period of time. Thus the rate of heat transfer to the surface and the "stagnation temperature" that the particle sees will be larger and ignition will occur earlier. The other run in Fig. 6 represents identical conditions except that the gas is pure nitrogen. RDX is a monopropellant and photocell records revealed that ignition did occur, but much further behind the shock front. As seen, detonation did not occur.

The wave characteristics for RDX-A in pure oxygen are shown in Fig. 7. From this run, it is not clear whether these conditions would result in a continuing self supported detonation. Similar conditions, but using a



full driver and air, are shown in Fig. 8. The Mach numbers are appreciably higher due to the high energy level of the driver. For this case there is insufficient tube length to determine whether detonation would be initiated or not.

### Analytical Results

During the year the NASA Gordon-McBride computer program was modified to accept condensed phase reactants. This program, along with the TIGER code, was then employed to calculate the Chapman-Jouquet detonation properties of RDX/air mixtures. The results are shown in Fig. 9. The pressure ratio increases drastically with RDX loading which, in the limit, would go to the extreme values associated with condensed explosives. The experimental values of pressure and velocity which were determined for RDX-A were found to be somewhat lower than these predictions. This is not surprising in that losses were not taken into account and, further, on the experimental side the wave takes an appreciable distance to go through the complete blast wave to detonation transition process.

Calculations similar to the above were made for a number of cases where the RDX is mixed in with a liquid fuel. The results are shown in Fig. 10. The high pressures to be expected with a liquid oxidizer are to be noted.

A numerical code developed by Eidelman and Burcat (1980, 1981) has been used to study the initiation of detonations by a strong blast wave in various dust-air and decane droplet-oxygen mixtures, including RDX-air mixtures. With the code it was possible to determine the effects of particle and droplet loading and reaction zone length upon the details of the initiation process. Thus Fig. 11, for instance, shows the variation of the pressure immediately behind the leading shock front for

various two phase mixtures and blast wave energies. The fuel heat release per unit volume is the same for curves 5, 7, and 8, shown in this figure; however, because of the different heating values of the fuels considered, the fuel loading is quite different and has an appreciable effect on the blast wave-detonation transition.

The numerical code employed makes it possible to examine the structure of the detonation in detail during the initiation process. Thus, Fig. 12 shows the variation of the mass velocity, particle velocity, sound velocity, and Mach number in an RDX-air detonation at a distance of 1.5 m from the center of the initiating blast wave. The structure shown corresponds to Case 8 in Fig. 11. The large plateau of nearly sonic velocity near the end of the 13 cm reaction zone appears to result from the interaction of the unburned solid particles and the gas flow. The Eidelman-Burcat code has also been used to compute the ground impulse produced by RDX-air detonations. A detailed exposition of these results is presented in two papers listed below.

#### PUBLICATIONS

Eidelman, S. and Sichel, M., "The Static and Dynamic Impulse Generated by Two Phase Detonations," paper submitted to Phys. Fl., Nov. 1980.

Eidelman, S. and Sichel, M., "Structure of Detonation Waves in Two Phase Media," in preparation.

#### PROFESSIONAL PERSONNEL

1. Professor J.A. Nicholls, Project Director
2. Dr. C.W. Kauffman, Associate Research Scientist,  
Co-Principal Investigator
3. Professor M. Sichel, Co-Principal Investigator
4. D.R. Glass, Research Scientist
5. D. Purmort, Graduate Student Research Assistant, awarded M.S. (Aerospace)
6. J. Draxler, Graduate Student Research Assistant, awarded M.S. (Mechanical)

#### INTERACTIONS, NEW DISCOVERIES, OTHER STATEMENTS

The experimental results to date appear to indicate that the larger RDX particles (150  $\mu\text{m}$ ) are easier to detonate with air than the smaller particles (10  $\mu\text{m}$ ). This is contrary to our expectations.

Calculations were made on the detonation properties of a heterogeneous fuel-air cloud wherein the fuel consisted of RDX particles in a liquid fuel. The pressures potentially available from some of these combinations appear to be very interesting.

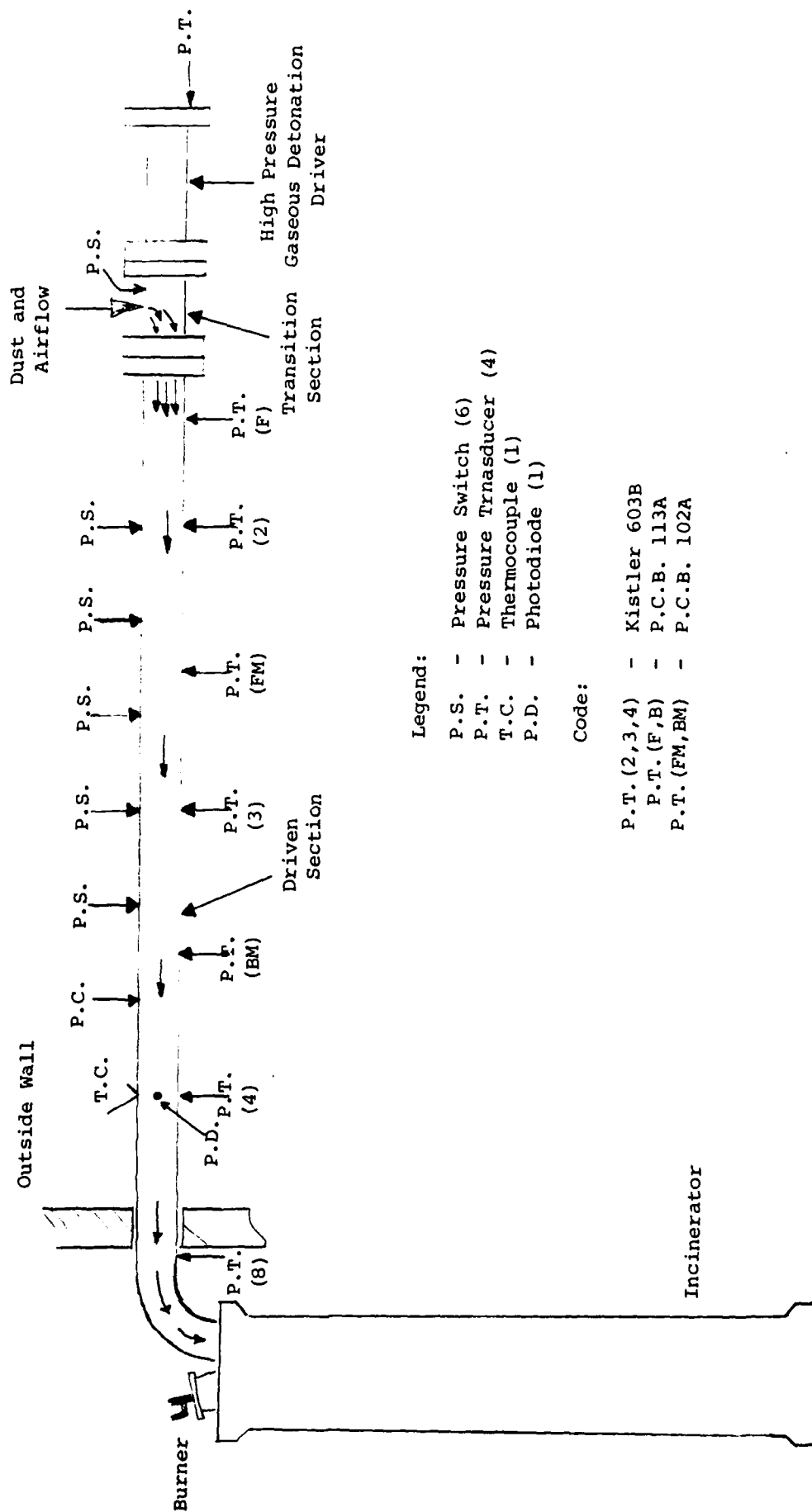
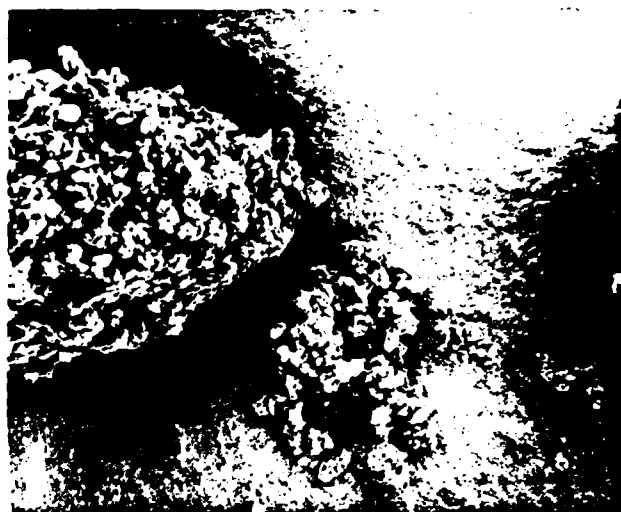


Figure 1. Schematic of Experimental Set-up



RDX-A 150  $\mu$ m 80 X



RDX-E 10  $\mu$ m 80 X

Figure 3. Electron Micrographs

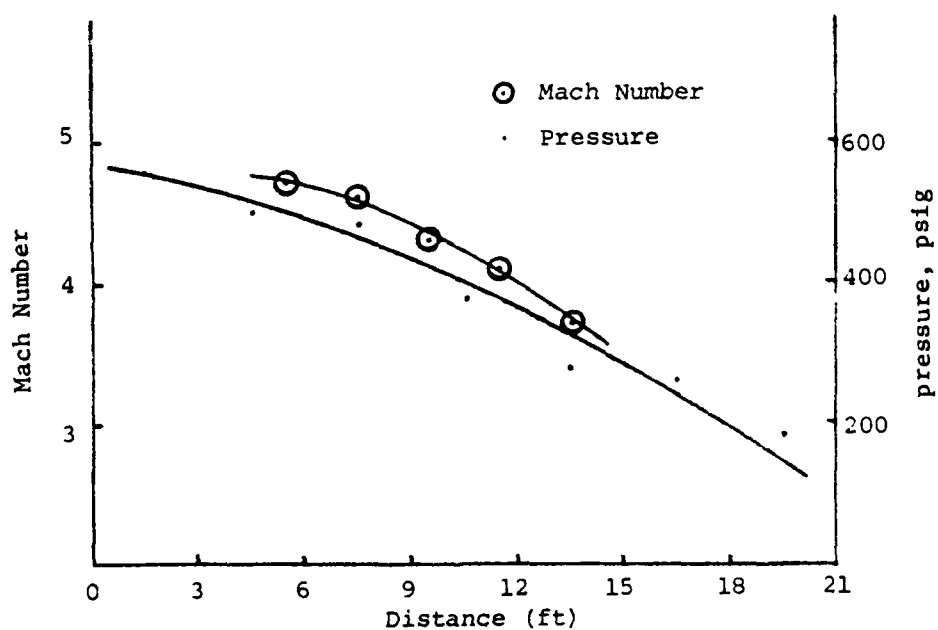


Figure 4. Calibration Curve, Mach Number and Pressure,  
No dust, Run #293, 1/4 driver, driver pressure  
119.3 psia

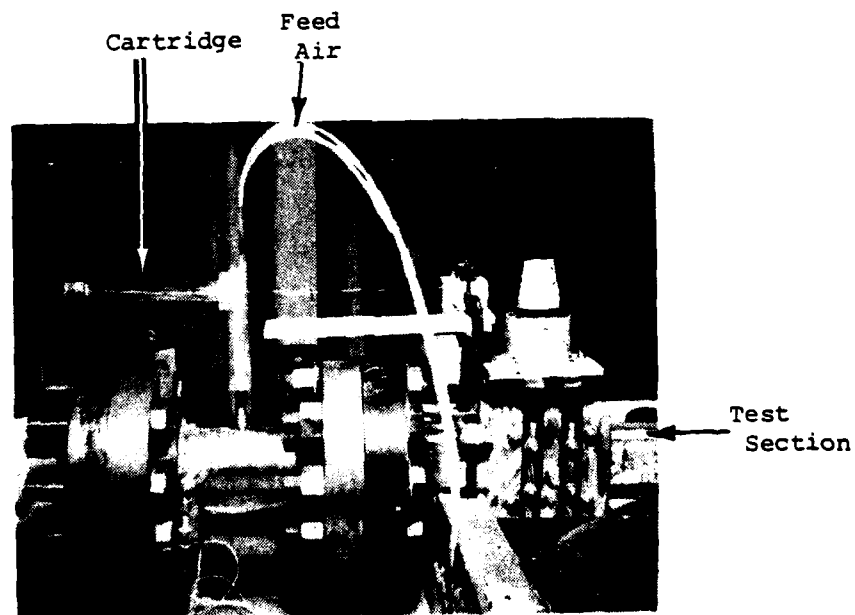
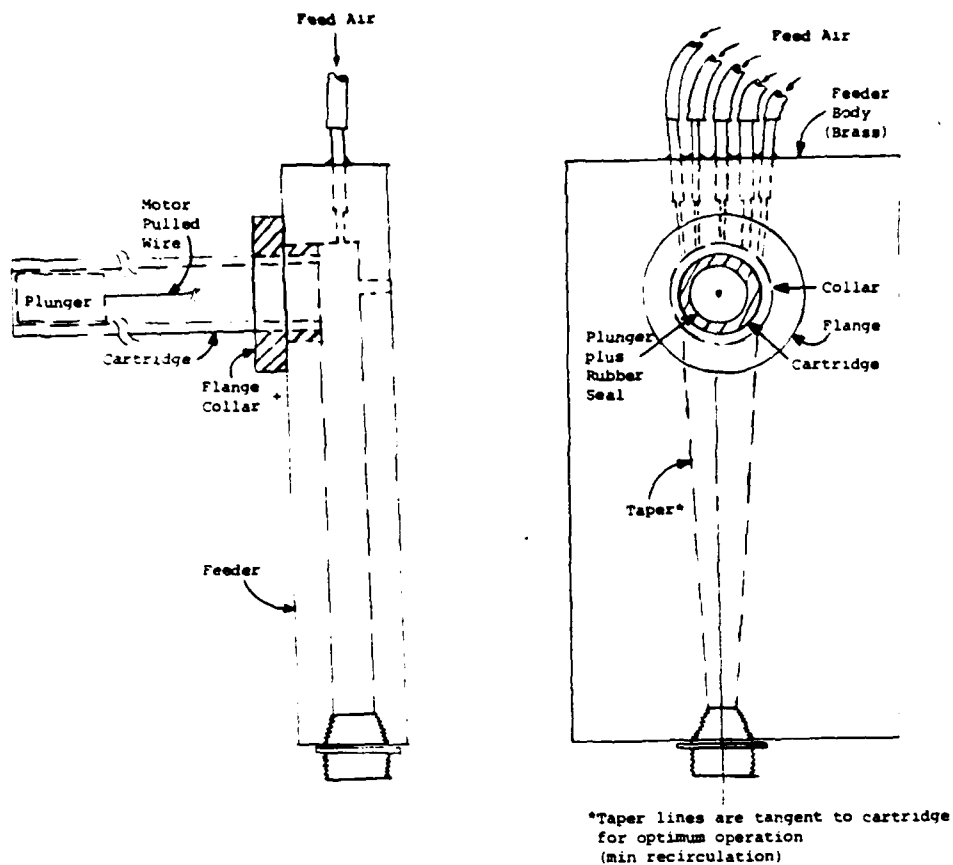


Figure 2. Dust Feeder

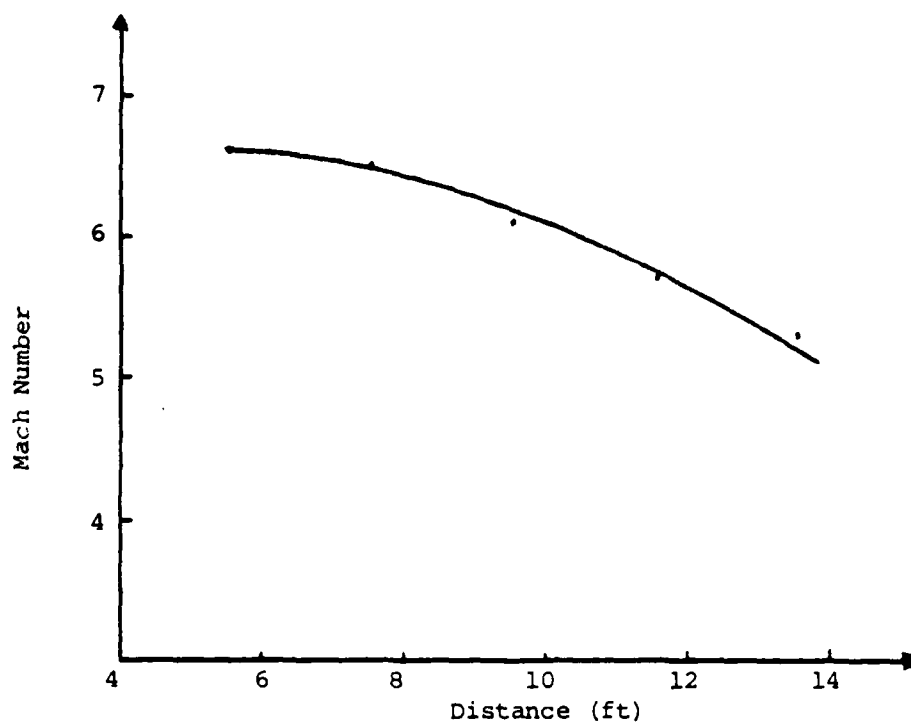


Figure 5. Wave Mach Number, RDX-E, Run #139  
 1100 gm/m<sup>3</sup>, 80% Air, 20% O<sub>2</sub>, Driver  
 Pressure 149.3 psia, 1/4 Driver.

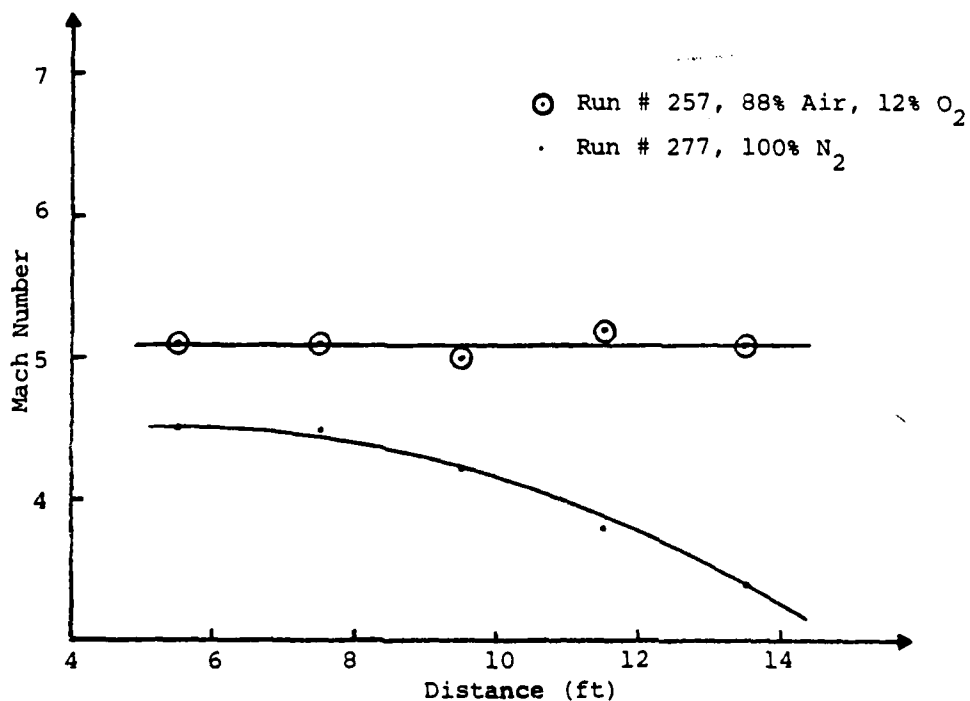


Figure 6. Wave Mach Number, RDX-A, 1300 gm/m<sup>3</sup>,  
 Driver Pressure 119.3 psia, 1/4 Driver.

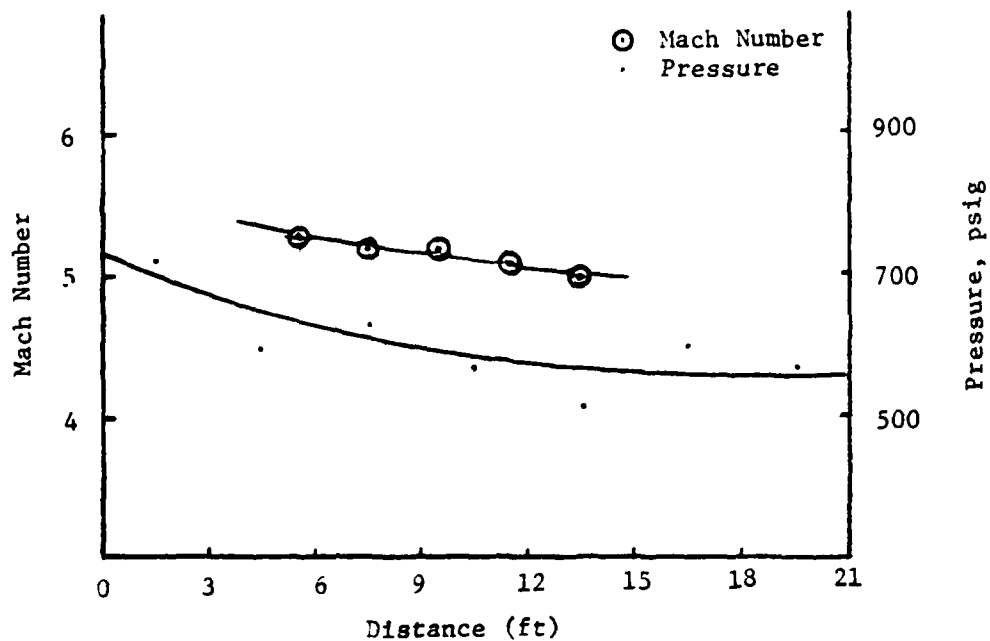


Figure 7. Wave Mach Number and Pressure, RDX-A, Run #292, 1300 gm/m<sup>3</sup>, 100% O<sub>2</sub>, Driver Pressure 119.3 psig, 1/4 Driver.

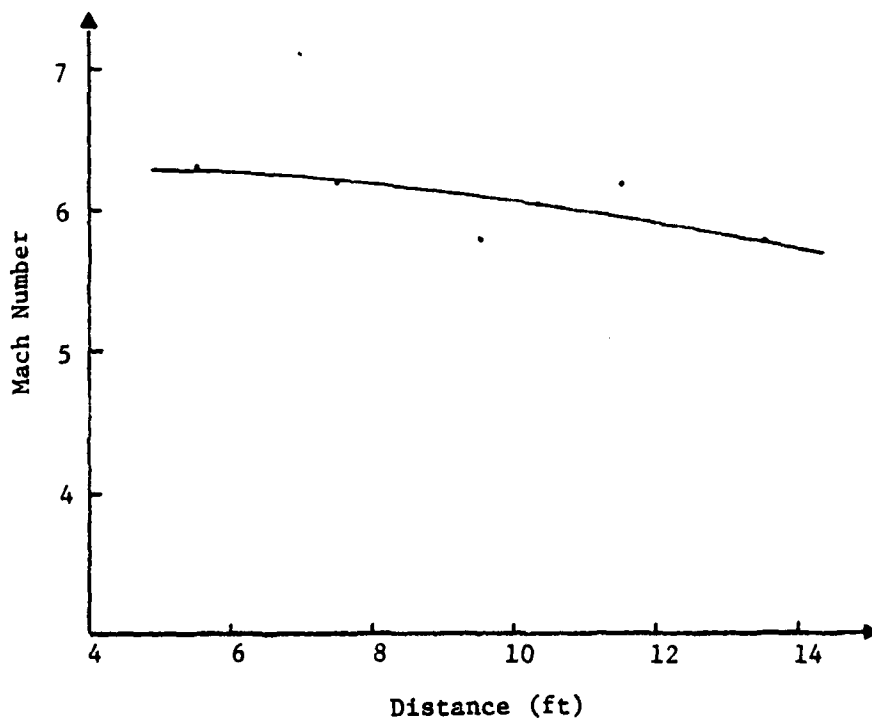


Figure 8. Wave Mach Number, RDX-A, Run #312, 1300 gm/m<sup>3</sup>, 100% air, Driver Pressure 119.3 psig, Full Driver.



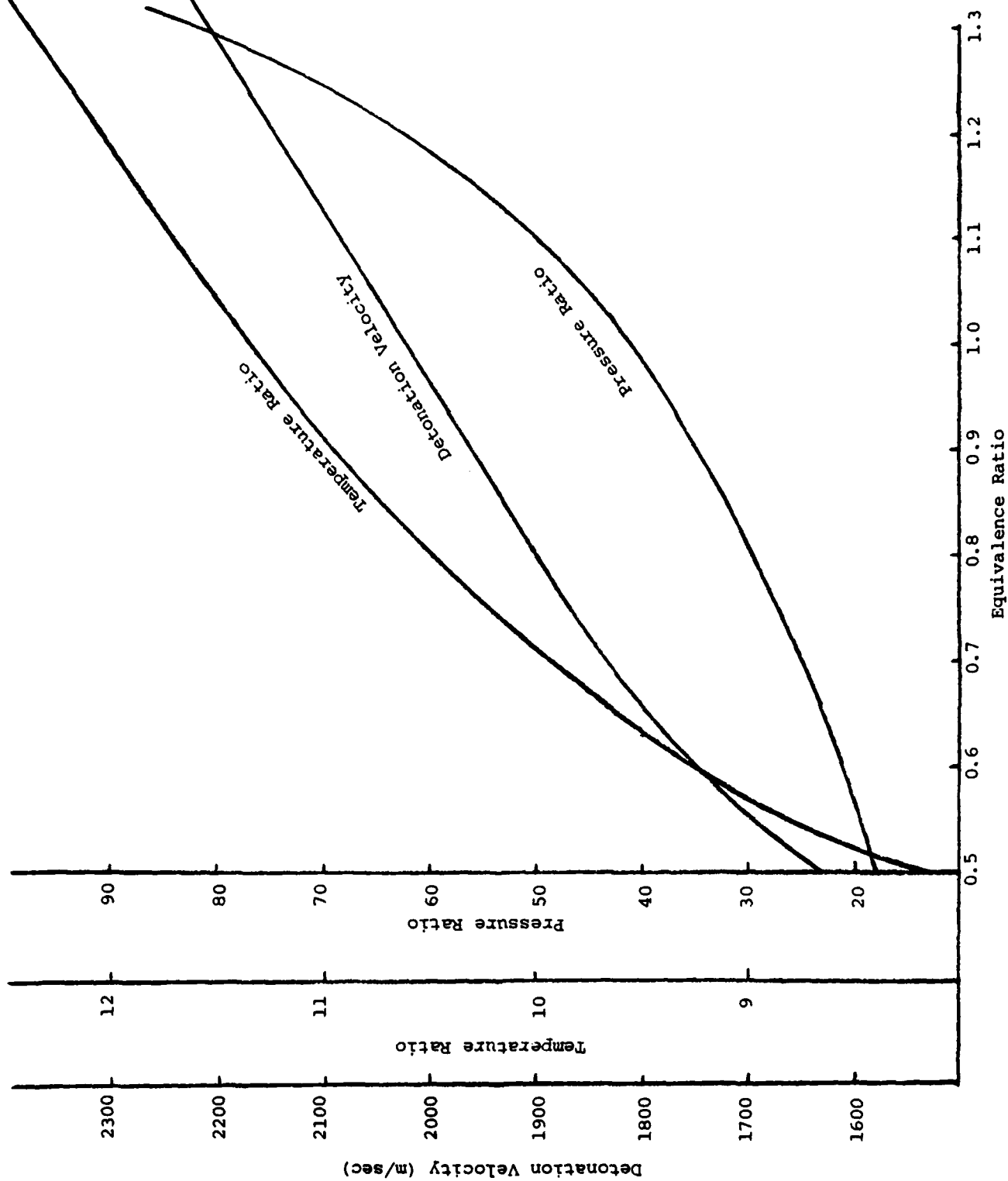
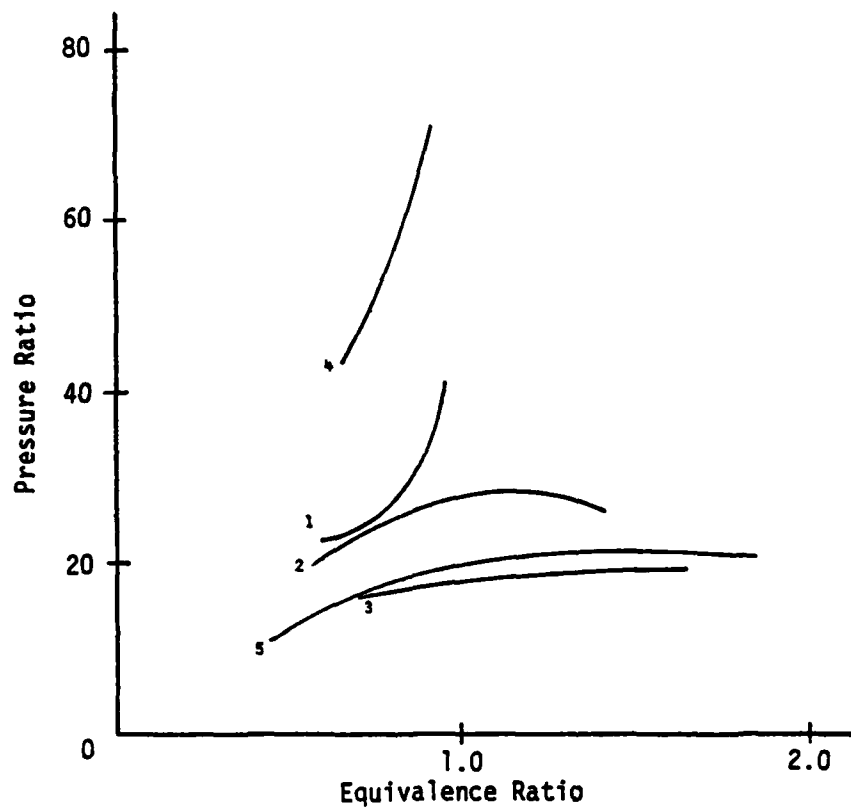


Figure 9. Detonation Properties of RDX/Air



- 1 RDX/Air
- 2 40% RDX + 60% Kerosene/60% Air + 40% Ammonium Perchlorate
- 3 Decane/Air
- 4 RDX/40% Air + 60% Ammonium Perchlorate
- 5 40% RDX + 60% Decane/Air

Figure 10. Detonation Pressure Ratios for Various RDX-Liquid Fuel Combinations with Air.

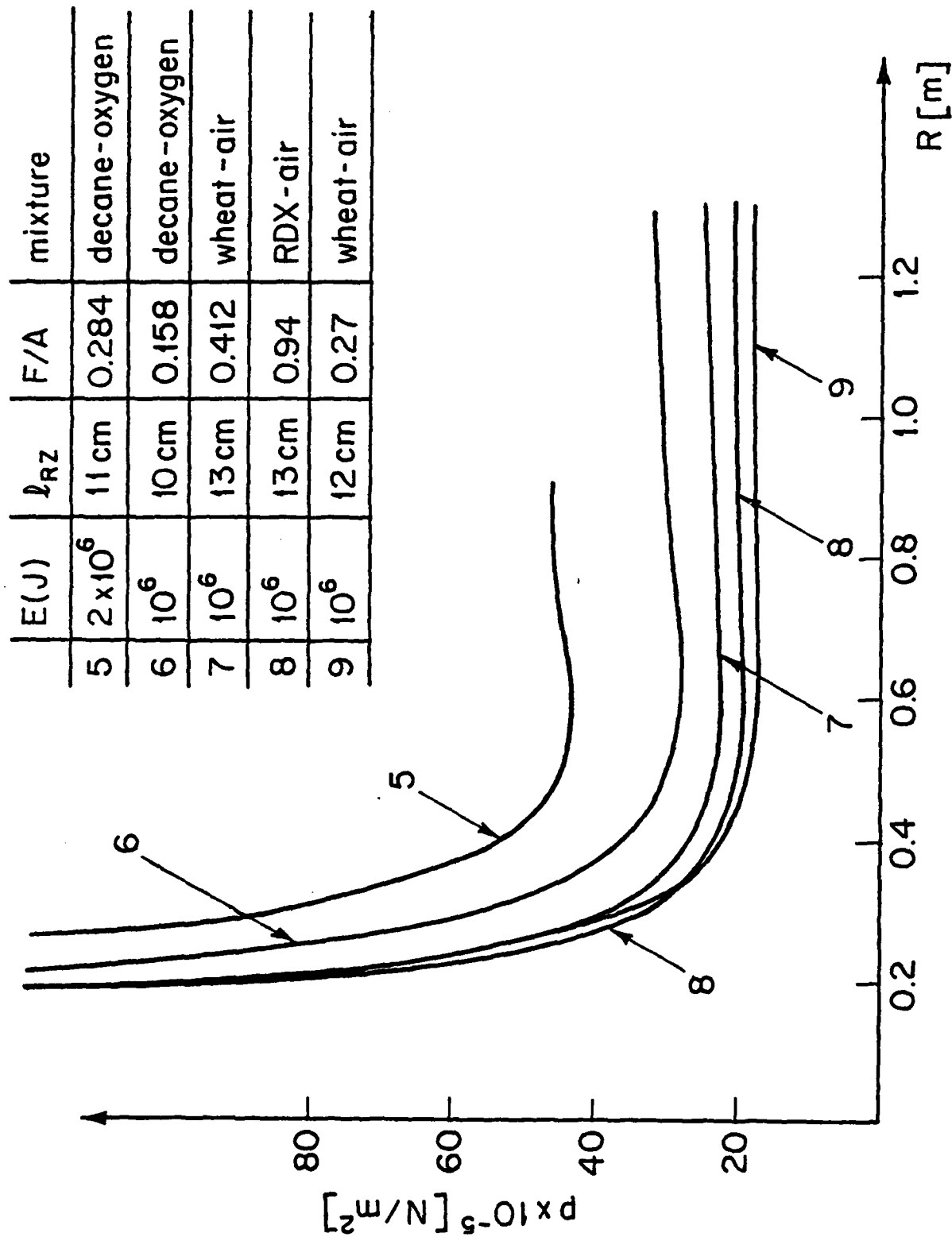


Figure 11. The Pressure Behind the Leading Shock Front versus Shock Radius for Various Combustible Mixtures.

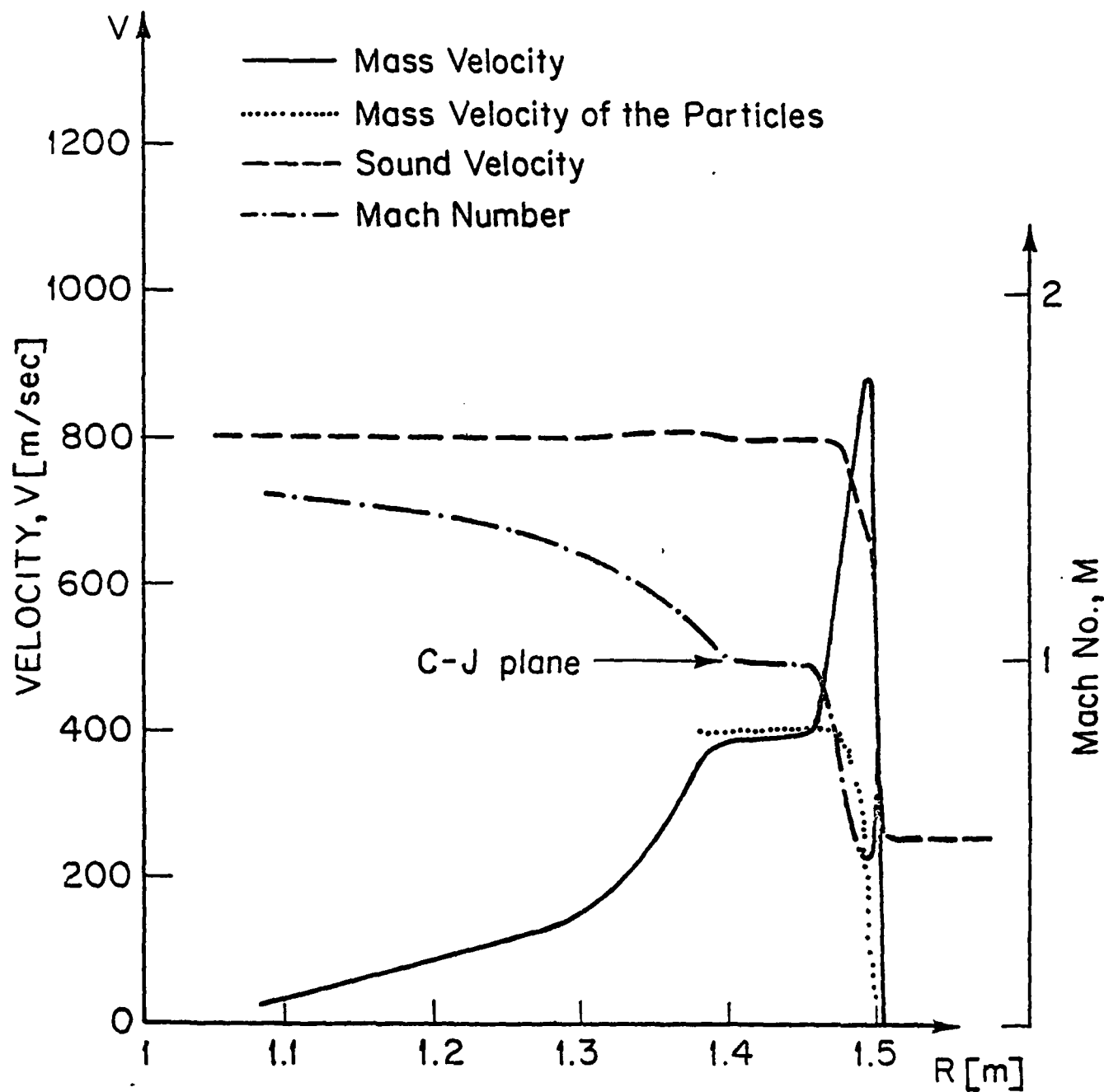


Figure 12. The Structure of the Detonation Wave at a Shock Radius of 1.5 m for Case 7 in Table I.

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